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THESIS

ANALYSIS OF THE DETERIORATION RATE OF SHIP HANDLING PROFICIENCY OF SURFACE WARFARE OFFICERS ON SHORE DUTY

by

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This thesis examines the deterioration of ship handling proficiency of Surface Warfare Officers on shore duty. A Surface Warfare Officer (SWO) develops ship handling proficiency during his or her first and second ship tours, then spends two or more years ashore. Upon returning to sea duty, an officer is expected to be proficient in ship handling even though it has been two years since the last shipboard evolution. Ashore SWOs were tested to determine whether their ship handling skills or knowledge about navigation rules had degraded over time. During the first phase of the experiment, subjects were immersed in a virtual environment to assess procedural knowledge of a ship handling task. The second phase of the experiment, designed to measure declarative knowledge of ship handling, consisted of a short written test. The results of the experiment showed no deterioration of SWOs ship handling skills over time. The results did show a significant deterioration of declarative knowledge of navigation rules. Actual or potential applications of this research include revising current Surface Warfare Officer training programs to account for the fact that not all knowledge is lost to memory equally. Periodic refresher training for SWOs on shore duty is also suggested by these results.

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ANALYSIS OF THE DETERIORATION RATE OF SHIP HANDLING PROFICIENCY OF SURFACE WARFARE OFFICERS ON SHORE DUTY

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This thesis examines the deterioration of ship handling proficiency of Surface Warfare Officers on shore duty. A Surface Warfare Officer (SWO) develops ship handling proficiency during his or her first and second ship tours, then spends two or more years ashore. Upon returning to sea duty, an officer is expected to be proficient in ship handling even though it has been two years since the last shipboard evolution. Ashore SWOs were tested to determine whether their ship handling skills or knowledge about navigation rules had degraded over time. During the first phase of the experiment, subjects were immersed in a virtual environment to assess procedural knowledge of a ship handling task. The second phase of the experiment, designed to measure declarative knowledge of ship handling, consisted of a short written test. The results of the experiment showed no deterioration of SWOs ship handling skills over time. The results did show a significant deterioration of declarative knowledge of navigation rules. Actual or potential applications of this research include revising current Surface Warfare Officer training programs to account for the fact that not all knowledge is lost to memory equally. Periodic refresher training for SWOs on shore duty is also suggested by these results.

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EXECUTIVE SUMMARY

This thesis examined the degradation of ship handling proficiency of Surface Warfare Officers on shore duty. After acquiring and routinely exercising ship handling skills during his or her first two at-sea tours, a Surface Warfare Officer typically rotates to an ashore duty assignment for two or more years. During this time, the officer's ship handling proficiency is not exercised, despite the fact that the officer will eventually return to sea and be expected to retain his or her previous skill level.

To assess the extent of ship handling proficiency degradation, a computer simulation of an underway replenishment and a written exam were created and administered to a number of Surface Warfare Officers currently assigned to the Naval Postgraduate School.

The experiment was divided into two phases, the computer simulation phase and the written exam phase. The purpose of the computer simulation phase was to assess the subject's ship handling skill when performing a routine, but demanding, ship handling task. During this phase, the subject was immersed in a virtual environment simulating the bridge of a ship via a Virtual Research V8 head-mounted active matrix display. The subject's task was to approach a replenishment ship, assume the proper station relative to that ship, and maintain station until the completion of the simulation. The subject maneuvered the approaching ship via verbal commands. Each subject performed one practice session to assess the maneuvering characteristics of the approaching ship. The practice session was followed by six trials, three each of two different simulated weather conditions. The computer simulation phase was followed by the written exam phase. The purpose of the written exam phase was to assess the subject's declarative knowledge of ship handling fundamentals and U.S. Coast Guard Rules of the Road. The written exam was divided into two parts, a multiple-choice section and an identification section. The multiple-choice section covered ship handling fundamentals in a written format, while the identification section presented various lighting and day-shape configurations for the subject to identify.

Results suggest that procedural knowledge of ship handling, as measured by a computer simulation, are robust to deterioration over time. Conversely, declarative knowledge, as measured by a written exam, presented statistically significant evidence of decline over time.

These results suggest ship handling training for SWOs returning to sea duty after shore duty should be weighted to address knowledge more heavily if it is more susceptible to decay.

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I. INTRODUCTION

A. RESEARCH PROBLEM

Piloting a surface vessel is a skill that requires many years of practice to master, if indeed one can ever master such a complex interaction of motion and forces. Like other human skills, "ship handling proficiency" is not a single, identifiable piece of knowledge, such as one's home phone number. Rather, it is a combination of facts learned in a classroom—the term "bow" meaning the front of a ship, for instance—and skills learned through experience—such as determining the right moment to reverse engines when docking.

Learning to be a good driver is a useful analogy. A good driver must know the traffic laws, such as speed limits, the meaning of a red light, and so on. The driver must also understand the function of the steering wheel, brake pedal, and all of the other controls used to operate an automobile. A prospective driver will learn the rules of the road and receive hours of practice prior to the driver license examination. However, to be a good driver, rather than merely a licensed driver, one must gain experience driving an automobile on the road.

Two kinds of knowledge contribute to the mastery of a skill. Memorizing and consciously recalling the significance of a red traffic light, for example, is *declarative knowledge*. However, steering a car out of an icy skid involves a different type of processing, one that, through practice, becomes an automatic, unconscious process. This is *procedural knowledge* (Willingham, Nissen & Bullemer, 1989). In the context of ship handling proficiency, one may learn the basic physical forces that cause a ship to move (i.e., declarative knowledge) before ever setting foot on a ship. A new surface officer will learn about wind, current, propellers, rudders, tugs and ground tackle in a classroom. However, it will take that officer many hours of experience to become proficient at handling a ship (i.e., procedural knowledge).

After acquiring a basic level of proficiency in ship handling, a Surface Warfare Officer (SWO) may not practice those skills for a long time. The normal career path of a SWO includes periods during which he or she will not exercise ship-handling knowledge. If officers lose skills during these periods, they must recover them later on at some cost to the navy. In addition, it is important to examine whether declarative knowledge and procedural knowledge decline at the same rate.

B. BACKGROUND

1. Declarative and Procedural Knowledge

Modern psychology has come to view human knowledge as a combination of two distinct memorial, or knowledge, systems. These two systems are commonly referred to as "declarative knowledge" and "procedural knowledge" (or, more recently, "non-declarative knowledge"). Earlier terms for the two systems of memory included "automatic" and "controlled," a distinction that perhaps more clearly conveys the hypothesized difference between the two systems.

In general, procedural knowledge is thought to be a system that operates without conscious effort (Squire & Cohen, 1984). Examples of this type of knowledge include the semantic and syntactic rules of the language a person uses and the skill of driving. People speaking and listening in their native language intuitively know and practice correct semantic and syntactic rules (i.e., good grammar), but are in most cases unable to articulate them (Lewicki, 1986). They unconsciously access rules of grammar to produce proper speech or raise attention to speech that does not adhere to these rules.

Procedural memory is also thought to support the acquisition and retention of skilled performance (Willingham, Nissen & Bullemer, 1989). Driving is a good example of this manifestation of procedural knowledge. A skilled driver recalls, without conscious effort, the procedural knowledge of a task such as shifting the manual transmission of a car into a different gear. The driver may, in fact, not even be aware that he or she has performed the task.

A number of studies have suggested that one can, in fact, acquire procedural knowledge without consciously knowing that one has even learned anything. For example, one study exposed subjects to a sequence of frames containing a target and required them to search for the target in each frame (Lewicki, Czyzewska, & Hoffman, 1987). Unbeknownst to the subjects, the location of the target in the seventh trial was predictable, based on the sequences of target location in four out of the six previous trials. Although none of the subjects indicated knowledge of the hidden pattern in post-experiment interviews, their performance on the seventh trial indicated that a significant level of learning took place. In essence, when the seventh trial commenced, the subjects' procedural knowledge acquired over the last six trials unconsciously cued them on where to look for the target.

Declarative knowledge, in contrast to procedural knowledge, is consciously retrieved when needed. Declarative memory is thought to support the retention of facts and the recollection of prior events. Examples of declarative memory include remembering what you ate for dinner last night, or being able to describe the appearance of your car. One can communicate this type of information explicitly to other individuals, who can then form a fairly accurate mental model of the same information in their declarative memory. Procedural memory, however, is impossible to pass on to another individual. For example, one can verbalize declarative aids to the skill of riding a bicycle, such as "pedal" and "hold the handlebars," but one can not verbalize the skill itself to another individual.

There are other differences between the two types of knowledge. In particular, procedural memory is believed to be fairly specific to the original learning situation and not easily accessible by the declarative system (Squire, 1994). In other words, to recall an example already discussed, the procedural knowledge required to unconsciously operate a manual transmission on a car is very specific to the task of shifting a manual transmission. Declarative memory, in contrast, allows the flexible use of knowledge in situations different from the original learning context. For example, one could adapt

declarative knowledge of the mechanics of an automobile engine to a wide variety of similar, but different, devices.

In addition to demonstrating differing mechanisms for declarative and procedural knowledge, studies have demonstrated an actual neurological basis for a distinction between the two memory systems. For instance, certain forms of brain lesions impair declarative, but not procedural, learning (Squire, 1986). A number of other studies focusing on amnesiacs support the theory that the two memory systems are, in fact, distinct. For example, in one study, amnesiac patients who have severely impaired declarative memory learned a classification task at the same rate as normal subjects (Reber, Knowlton, & Squire, 1996). However, the amnesiacs were impaired on transfer tests that required flexible use of their task knowledge. In other words, the amnesiacs learned the procedural aspect of the task as well as normal subjects, but were impaired in declarative knowledge of the task.

Numerous studies on amnesia, other neurological disorders, and aging have revealed that procedural knowledge and declarative knowledge are, in fact, distinct. The two memory systems are not equally robust and are not stored or processed in the same way by the human brain. It appears from studies that declarative knowledge is the more fragile of the two forms of memory, while procedural knowledge is more robust, but less flexible.

2. Acquisition and Utilization of Ship-handling Skills

The acquisition and retention of ship-handling skills is central to the training of a new ensign in the surface community. At the Surface Warfare Officer School in Newport, R.I., practiced instructors teach new ensigns the fundamentals of ship handling in a classroom setting, supplemented by simulator training. Only upon arriving at their first ship, however, do aspiring surface warfare officers obtain most of their knowledge. They will typically get frequent opportunities to learn and practice ship-handling skills under the watchful eyes of more-experienced officers. Newly reporting surface officers will generally stand watch as the Conning Officer, while a more senior officer will

supervise in the role of Officer of the Deck. The Conning Officer is the person who directly controls the movement of the ship with verbal commands to the personnel operating the ship's helm (steering control) and throttle (engine control). New officers, during their first shipboard tour, will spend many hours as Conning Officer and likely become proficient in a variety of ship-handling tasks, including very difficult tasks such as underway replenishment and plane guard. The goal of all new surface officers on their first ship is to become qualified as Surface Warfare Officers (SWO).

The SWO qualification is analogous to an aviator's "wings" or a submariner's "dolphins." To attain their SWO qualification, officers must satisfactorily perform a variety of ship-handling tasks and demonstrate before a board of senior officers a comprehensive grasp of essential surface warfare knowledge. Toward this goal, new officers are given many opportunities to exercise their ship-handling skills and spend many hours on the bridge. However, once they have earned their SWO qualification, usually on their first ship, officers may have far fewer opportunities to exercise their ship-handling skills. Though officers may still regularly stand watches on the bridge, they have less incentive to rigorously practice ship-handling skills, and they will most often act as the supervisory Officer of the Deck rather than the Conning Officer. In many cases, SWO qualified officers do not spend any time at all on the bridge because their watch stations involve some other aspect of the ship's operation, such as engineering. In general, officers who have obtained the SWO qualification will seldom directly practice ship handling as Conning Officer.

Following an initial at-sea period on two different ships, officers return to shore duty, typically for about two years. Prior to returning to sea duty after the first ashore period, officers will normally attend Department Head School in Newport, Rhode Island. Although Department Head School makes some effort to refresh ship-handling skills through both classroom instruction and simulator exercises, this training is neither as extensive nor as demanding as the initial at-sea qualification process. In total, officers can expect about 20 hours of ship-handling refresher training while at the school. The

inclusion of refresher ship-handling training implies an assumption that the ship-handling skills of SWOs deteriorate while on shore duty.

It is true that, after shore duty, officers may return to a ship not having stood a bridge watch for at least two years and, in most cases, longer than that. If, after SWO qualification, officers stood most of their watches somewhere besides the bridge, it could be as long as four or five years since they practiced ship-handling skills in a significant manner. Nevertheless, upon arrival at their first ship after shore duty, officers will be expected to be expert ship handlers. The ship-handling refresher training at Department Head School is an attempt to address this issue. However, the structure of the refresher training, with its emphasis on simulator exercise over classroom instruction, implies a pattern of knowledge deterioration that may not be accurate. And, SWOs on shore duty are not routinely tested to determine whether or not such deterioration actually occurs. In fact, it may be the case that declarative knowledge (e.g., "bow means the front of the ship") degenerates at a different rate than procedural knowledge (e.g., "when to reverse the engines when docking"), which is learned by experience.

The ratio of simulator to classroom training in the ship-handling refresher phase of Department Head School is 16 to 1. As mentioned earlier, classroom training imparts primarily declarative knowledge. And, although ship-handling simulator training assumes competency in appropriate declarative knowledge, it exercises primarily procedural knowledge. The overwhelming emphasis on simulator exercises implies an assumption that declarative knowledge is much more robust to deterioration than is procedural knowledge. This assumption may not be correct.

Military training of many varieties, not least the extensive training that goes into creating a proficient Surface Warfare Officer, is expensive in terms of both time and money. If the skills of SWOs deteriorate during periods of inactivity, that represents a very real cost to the navy. Not only has the navy lost some of the value of its initial investment in its officers, but it also must expend additional time and money to retrain the officers before they return to sea duty. Therefore, if refresher training is indeed justified by a measurable decline in skills, it would be prudent to selectively tailor that refresher

training to target those skills that have declined. Other communities within the navy and other branches of the armed services face similar dilemmas, and this line of research may benefit their training programs, as well.

3. Underway Replenishment

The specific ship-handling task modeled in the computer simulation phase of the experiment is underway replenishment (UNREP). This particular task was chosen because it is one of the most challenging ship-handling tasks a Surface Warfare Officer can expect to encounter on a routine basis. It is also one of the tasks at which SWOs must become proficient in order to achieve their qualification.

The main purpose of UNREP is to replenish fuel and stores at sea. The replenishing of vessels while underway, which essentially eliminates the need to return to port, is one of the cornerstones of the U.S. Navy's ability to operate globally. UNREP is particularly important when ships must make long transits or remain on station for extended periods.

Replenishment at sea is normally accomplished by means of fuel hoses suspended from steel cables that are under tension between a supply ship and another vessel. The system of steel cable, tensioning equipment and connection point on each ship from which a fuel hose is suspended is called a rig. Rigs can be used to transfer, in addition to fuel, pallets of food, parts, ammunition or other supplies, and underway replenishment has become a common evolution for ships at sea.

Replenishment at sea does carry risk, however: ships must steam very close to one another for extended periods; constant, minute adjustments must be made in both course and speed to maintain proper separation between the two ships; and equipment failure, miscommunication, inattention or poor ship handling can easily cause a collision. Because of these dangers, replenishment at sea is a delicate and demanding ship-handling task, although years of refining procedures have made serious accidents rare.

For this experiment, UNREP is used as a representative ship-handling task to assess subjects' procedural knowledge of ship handling. Because of the specificity of procedural memory discussed above, it is possible that subjects can perform well on the UNREP task, but not as well on other ship-handling tasks. However, as UNREP encompasses many of the individual skills an officer must acquire in order to be proficient at ship handling, UNREP indeed appears to represent the procedural aspects of ship handling as a whole.

C. PURPOSE

The purpose of this thesis is to determine whether Surface Warfare Officers' ship-handling skills and knowledge deteriorate over time. The hypothesis is that SWOs' ship-handling abilities will deteriorate at a rate different from that of maritime declarative knowledge. The experiment consists of a mixed-design model with time away from sea serving as the between-subject variable.

It was assumed that there would be a high degree of correlation, for Surface Warfare Officers, between the amount of time since standing bridge watches while on sea duty and the current quarter of instruction at the Naval Postgraduate School (NPS). It was thought that by assigning subjects to one of two groups based on current quarter of instruction (i.e., first quarter students as one group, seventh quarter students as another), each group would be homogenous in terms of time away from bridge watch at sea.

Two different lighting conditions and two different orderings of the computer simulation trials served as the within-subject independent variables. The dependent variables measured were distance from correct station (in meters) for the computer simulation trials and number of questions answered correctly for the written test. The data collected were used to determine if the dependent variables changed significantly as a function of the independent variables.

It was expected that procedural knowledge, as measured by the computer simulation, would be robust to deterioration over time and, conversely, that declarative knowledge, as measured by the written exam, would be much less robust over time. The

distinction between the two types of ship-handling knowledge should, therefore, manifest itself as a difference in the two groups' performance on the written exam measuring declarative knowledge, but no significant difference between the groups on the computer simulation measuring procedural knowledge.

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II. METHODS

A. SUBJECTS

Eleven military observers with a mean age of 30 years and sigma of three years with normal or corrected to normal vision volunteered for this experiment. All subjects, Naval Postgraduate School graduate students, were designated as Surface Warfare Officers (SWO). The subjects were divided into two groups: first quarter students or graduating seventh quarter students. In order for a subject to participate in this experiment, he or she must have performed at least one UNREP and acted as a conning officer or officer of the deck prior to arriving at the Naval Postgraduate School. Informed consent was obtained from all observers.

B. APPARATUS

1. Virtual Environment Generation

Subjects viewed the virtual environment through a Virtual Research V8 head-mounted active matrix LCD VGA display with a field-of-view of approximately 60 degrees. Head positions were tracked with a 3space Polhumus tracking system and the ship position was manipulated by a BG Systems FlyBox joystick. The virtual environment was rendered on a Silicon Graphics Onyx Reality Engine. Software used to model the simulation was MultiGen Creator (version 14.5), Vega (version 3.2), Vega Marine module (version 3.2), and LynX graphical user interface (version 3.2) from MultiGen-Paradigm Inc.

2. Flag Configuration for Computer Simulation

During a normal daylight underway replenishment, the conning officer of the receiving vessel determines the lateral distance to the supply vessel by use of a visual aid called a phone and distance line. The phone and distance line, termed as such due to its

dual purpose as a visual aid and communication line, is shot between the vessels, via a reduced charge rifle cartridge, once the receiving vessel is approximately in station alongside. Colored flags are attached to the phone and distance line every five feet (1.5 meters). The colored flags follow a repeating pattern of red, yellow, blue, white and green [Figure 1].

Figure 1: During an UNREP, colored flags (red, yellow, blue, white, and green) are used as a visual aid to estimate the distance to the supply ship.

On an actual phone and distance line, the distance in feet from the receiving ship to the supply ship is also painted on each flag. For example, the first three flags counting away from the receiving ship are a red flag with the number 5, a yellow flag with the number 10, and a blue flag with the number 15. The flags of the phone and distance line connecting the supply ship and receiving ship in the simulation did not have numerals on them.

The normal distance between the supply ship and receiving ship varies with the sea-state, type of ships involved, and the weather. In most cases, the two ships are approximately 90 feet to 120 feet apart (Crenshaw, 1975), though ships can extend to approximately 300 feet apart before refueling hoses are in danger of disconnecting. For purposes of the experiment, the correct lateral separation was defined at 80 feet due to the HMD's narrow field-of-view. The subjects were made aware of the correct lateral separation for the experiment.

C. PROCEDURE

1. Design of Experiment

The experiment was divided into two phases, procedural phase and declarative phase. During the procedural phase subjects were immersed in a virtual environment and assumed the responsibilities of a conning officer of a cruiser. As conning officer, the subject was required to perform six underway replenishments with a simulated supply vessel. The six trials were divided into three daytime and three dusk UNREP simulations. During the daytime simulation, the supply ship maintained a speed of 13 knots. The dusk condition illumination was reduced by 30 percent and the supply ship altered speed in a random range between 13.8 and 14.4 knots to simulate the effects of a higher sea-state. The six trials were randomly ordered for each subject. Each simulated UNREP was six minutes in length.

At the completion of the procedural phase, the subject was given a two-minute rest before the start of the declarative phase. The declarative phase was a written exam that lasted approximately 20 minutes. Refer to Appendix A to review the exam.

Before the first procedural trial commenced, subjects were briefed on the ship handling task of an underway replenishment. Once the subject was familiarized with the simulation task the experimental trials began. The subject controlled the cruiser's course and speed by issuing verbal commands to the test monitor. The test monitor, in turn, acted as helmsman and lee helmsman of the simulated cruiser, controlling its course and speed via a FlyBox controller. Within the simulation, the output of the FlyBox was

adjusted to accurately mimic the handling characteristics of a Ticonderoga-class cruiser in terms of speed and acceleration, turning radius, advance and transfer.

Before beginning the first trial, subjects were allowed one practice run six minutes in length. The beginning position of each vessel for each trial is depicted in Figure 2. Figure 3 depicts the subject's view through the HMD of an approach in progress. The purpose of the practice run was to familiarize the subject with the handling characteristics of the simulated receiving vessel, the appearance of the simulated supply vessel, and to practice verbal commands. No data collection was performed during the practice run and subjects were free to ask questions.

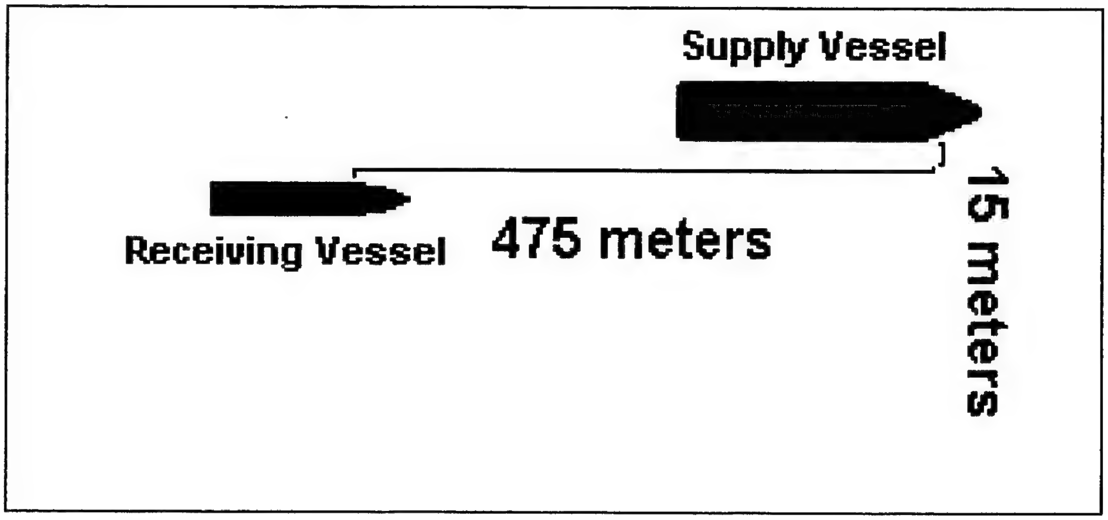

Figure 2: Starting positions of the receiving ship and the supply ship.

During the dusk lighting condition trials, the supply ship continually altered speed in a range between 13.8 and 14.4 knots. The simulated supply ship followed a slightly twisting path that brought her course alternately to the left and right of 000° [Figure 4].

The supply ship and cruiser position and heading were recorded every five seconds. The speed of the supply ship and cruiser were displayed on a monitor every five seconds.

Figure 3: View from receiving ship of approach in progress.

Differences between the day and dusk conditions were as follows:

- Ambient Light Level: The light level for the dusk condition was reduced approximately 30% compared to the day condition.
- Supply Ship Speed: During the day condition trials, the supply ship maintained a speed of 13 knots. During the dusk condition trials, the supply ship altered speed in a range between 13.8 and 14.4 knots to simulate the effects of a higher sea-state.

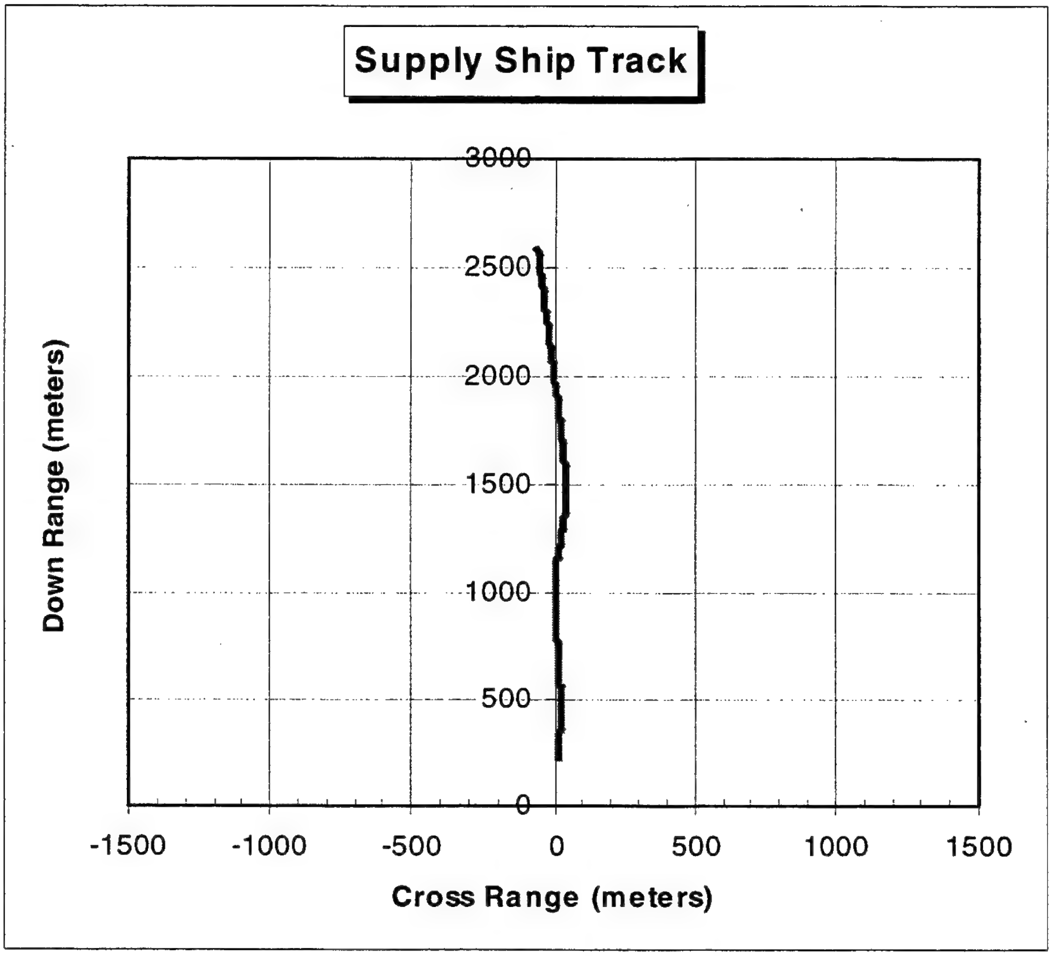

Figure 4: Supply ship track.

The declarative phase assessed subjects' knowledge of ship handling fundamentals and the International Rules of the Road. During this phase of the experiment, the subject was given a multiple choice and short answer written exam consisting of 18 questions [Appendix A]. Of the 18 questions, eight were multiple choice questions concerning ship handling fundamentals and regulations as described in *Naval Shiphandling* and the International Regulations for Prevention of Collisions at Sea, or "Rules of the Road". The remaining ten questions asked the subject to visual identify the type of, or task being performed by, vessels depicted in a series of illustrations. Each illustration presented the day shapes or running lights of a type of vessel typically encountered while underway.

The subject was allowed 20 minutes alone in a room to complete the exam. The subjects were not allowed to use references or a calculator. The experiment concluded upon the subject's completion of the written exam.

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III. RESULTS

A. SEPARATION OF GROUPS FOR ANALYSIS

A comparison of current quarter of instruction and time away from bridge watch at sea for the subjects of the experiment revealed that, in line with expectations, students near the end of their time at NPS had spent at least a year and half away from sea. However, students near the beginning of their instruction at NPS exhibited a wide range of time, between one and 18 months, away from sea. There are many reasons for this phenomenon, including ship schedules, billet assigned while on sea duty, and personal circumstances.

Thus, experimental group one represents subjects who had, at the time of the experiment, spent anywhere between one to 18 months away from bridge watch on sea duty. Experimental group two represents those who had spent more than 18 months away from bridge watch on sea duty.

B. PHASE I : SIMULATED UNDERWAY REPLENISHMENT

1. Measures of Performance

The computer simulation phase of the experiment consisted of 11 subjects conducting six simulated underway replenishments each, for a total of 66 observations. Subjects were assessed on three separate measures of performance:

- Time to Station: The amount of time, measured in seconds, from the beginning of a trial until the subject maneuvered the receiving vessel to within 100 meters of the target station.
- Overall Error: Mean difference in position between the receiving vessel and the target station over the duration of an entire trial.

- Post-Approach Error: Mean difference in position between the receiving vessel and the target station over the portion of each trial subsequent to the receiving vessel maneuvering within 100 meters of the target station.

The distinction between overall error and post-approach error was made to account for differing styles of ship maneuver. The environment in which Surface Warfare Officers learn how to maneuver into station influences how they will conduct an evolution such as UNREP. Some commanding officers advocate a fast, aggressive approach at high speed, while others prefer a slower, more deliberate approach. By making a distinction between overall error and post-approach error, the environment in which the subjects acquired their ship handling skills will not confound an assessment of their performance. Furthermore, making a distinction between overall error and post-approach error allows an analysis of whether or not there is a systematic difference between groups in time to reach station.

2. Statistical Analysis

Statistical analysis of the data was done using S+ 2000 software from MathSoft, Inc., and Arc 0.98 software (Cook and Weisberg, 1999).

An initial examination of the time to station data using normal probability and histogram plots suggested that the data were not normal [Figure 5]. A Kolmogorov-Smirnov goodness-of-fit test supported the hypothesis that the time-to-station data did not follow a normal distribution. As a result of the initial analysis, a Box-Cox power transformation ($time^{-0.67}$) was performed to make the data more amiable to multi-factor analysis of variance (MANOVA) [Figure 6].

Similarly, an initial analysis of the overall error data suggested that these data did not adhere to a normal distribution [Figure 7]. As with the time-to-station data, a power transformation ($error^{-0.27}$) was performed to reshape the data distribution to a more symmetrical form [Figure 8].

An analysis of post-approach error (overall error corrected for approach time) indicated that the data did not follow a normal distribution [Figure 9]. A power transformation was performed on the post-approach error data to make them more symmetrical for MANOVA [Figure 10].

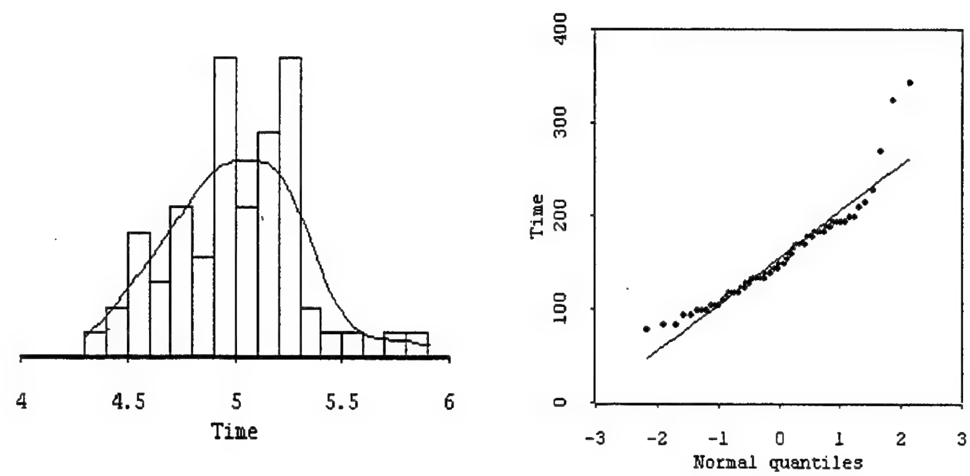


Figure 5: Histogram and probability plot of time to station data.

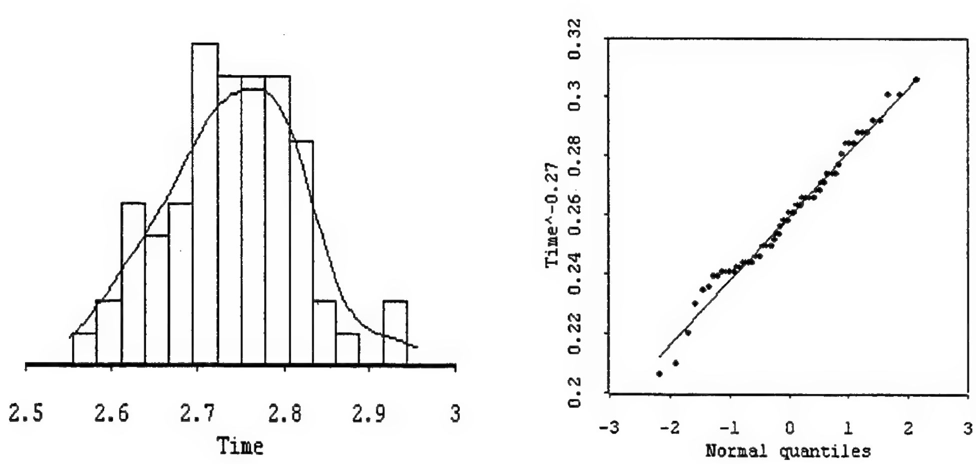


Figure 6: Histogram and probability plot of time to station data after transformation.

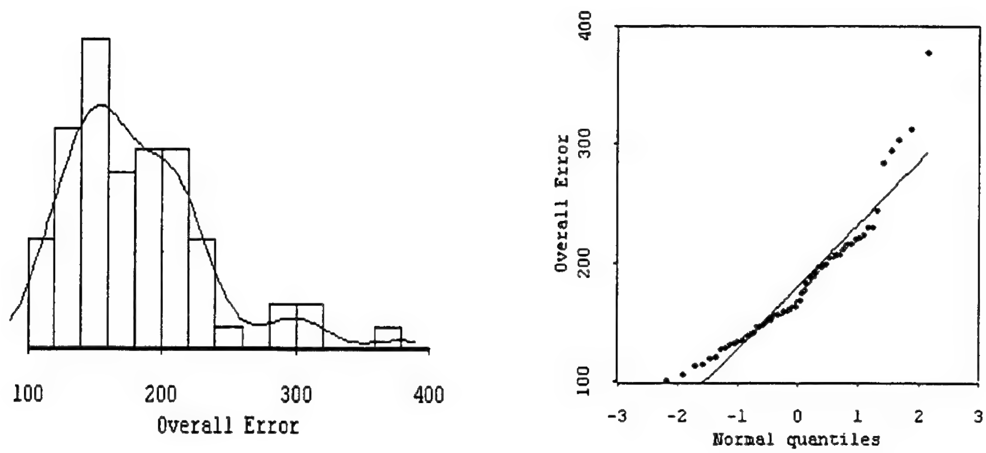


Figure 7: Histogram and probability plot of overall error data.

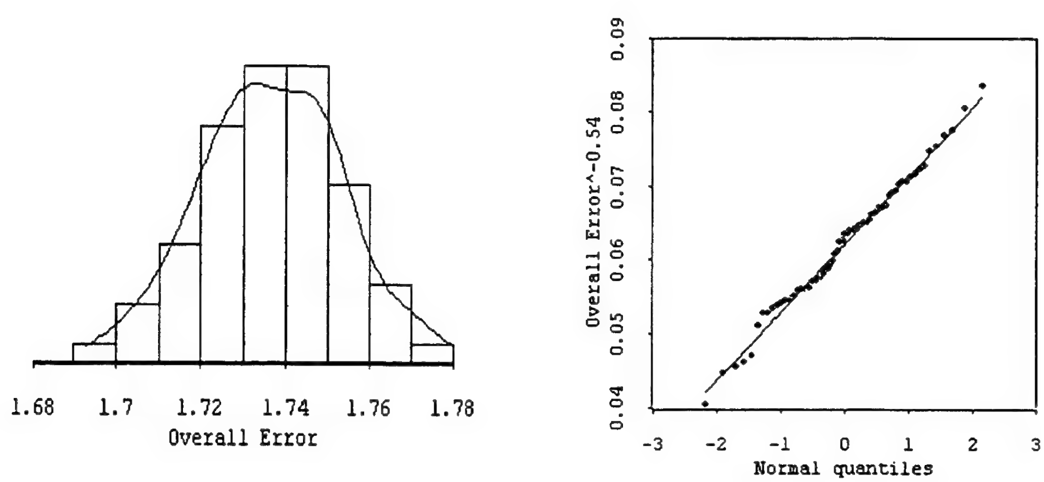


Figure 8: Histogram and probability plot of overall error data after transformation.

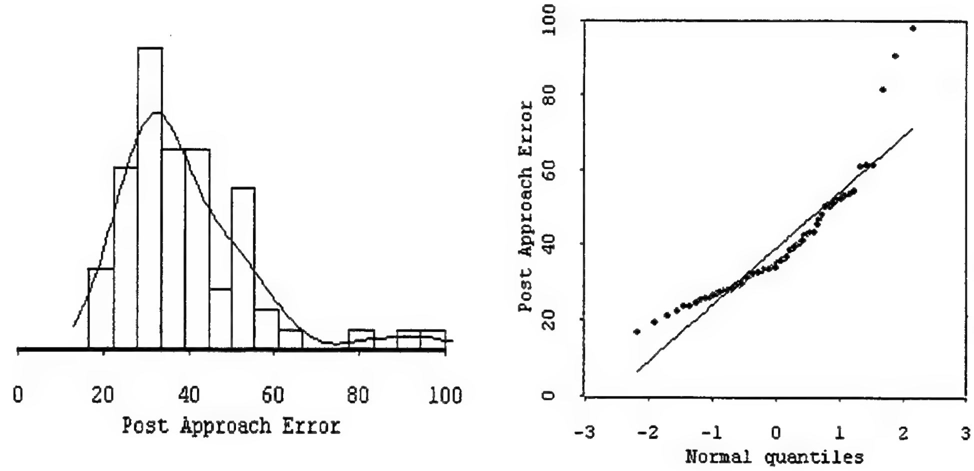


Figure 9: Histogram and probability plot of post-approach error data.

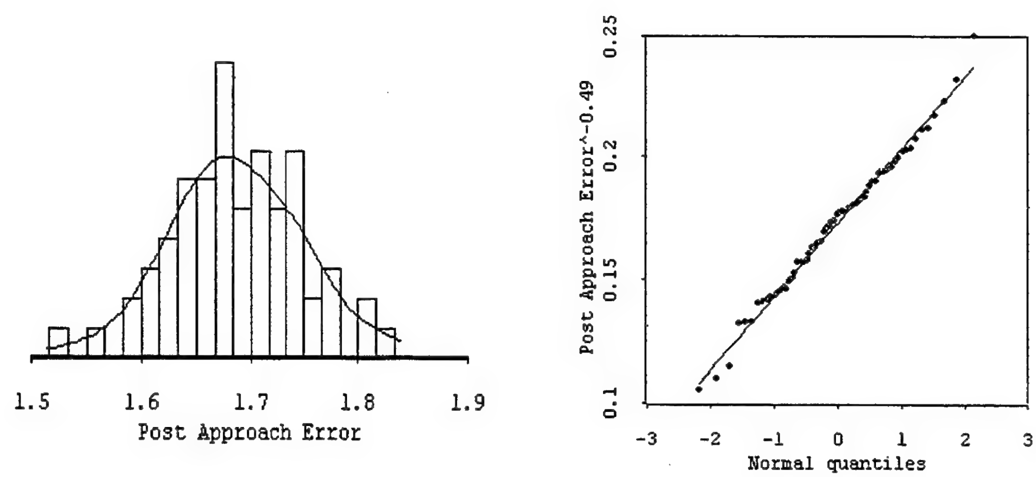


Figure 10: Histogram and probability plot of post-approach error data after transformation.

A two-factor MANOVA did not reveal significant effects due to the two lighting conditions (Pillai-Bartlett Trace $F_{(1,62)}= 0.104$, $p = 0.08$) or two subject groups (Pillai-Bartlett Trace $F_{(1,62)}= 0.0106$, $p = 0.89$). The interaction term lighting:subjects was also not significant (Pillai-Bartlett Trace $F_{(1,62)}= 0.009$, $p = 0.90$).

3. Observations

The results of the computer simulation phase of the experiment were suggestive, but were not statistically significant evidence of a decline in procedural knowledge over time. Both groups statistically performed equally well overall, with no significant differences in any measure of performance for either condition. Group 1 performed slightly better than Group 2 in overall stationing error and post-approach error under both lighting conditions, with the exception of overall error in the day condition [Figure 11].

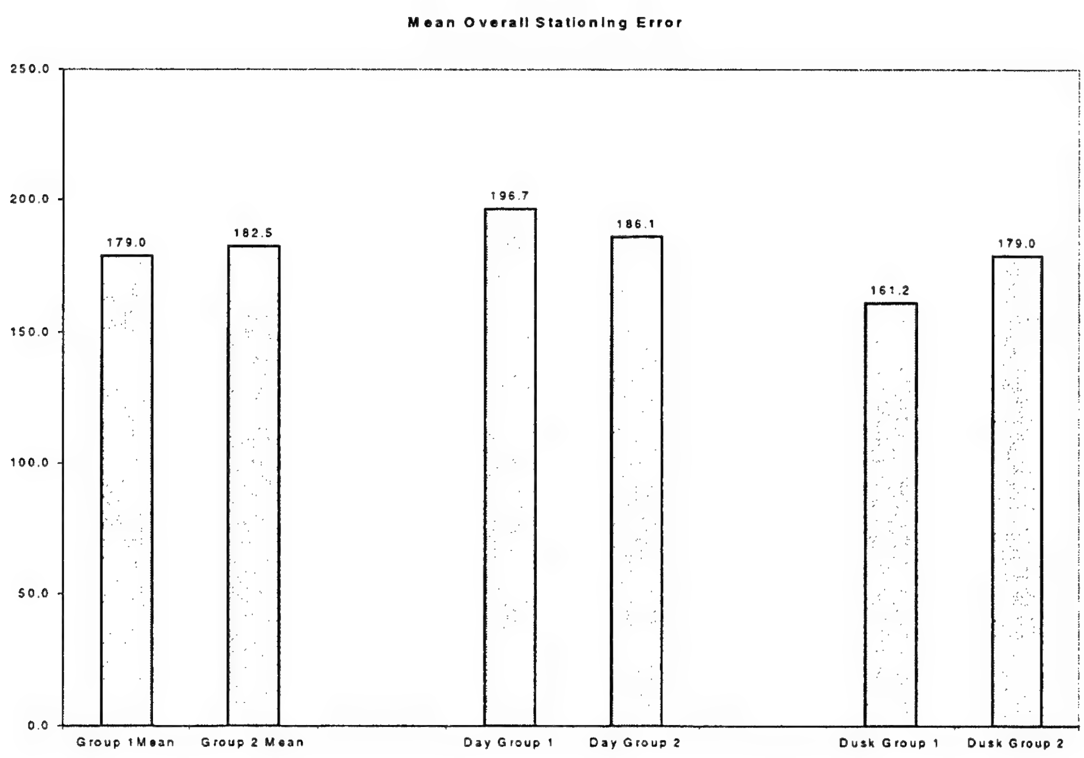


Figure 11: Comparison between groups for overall error.

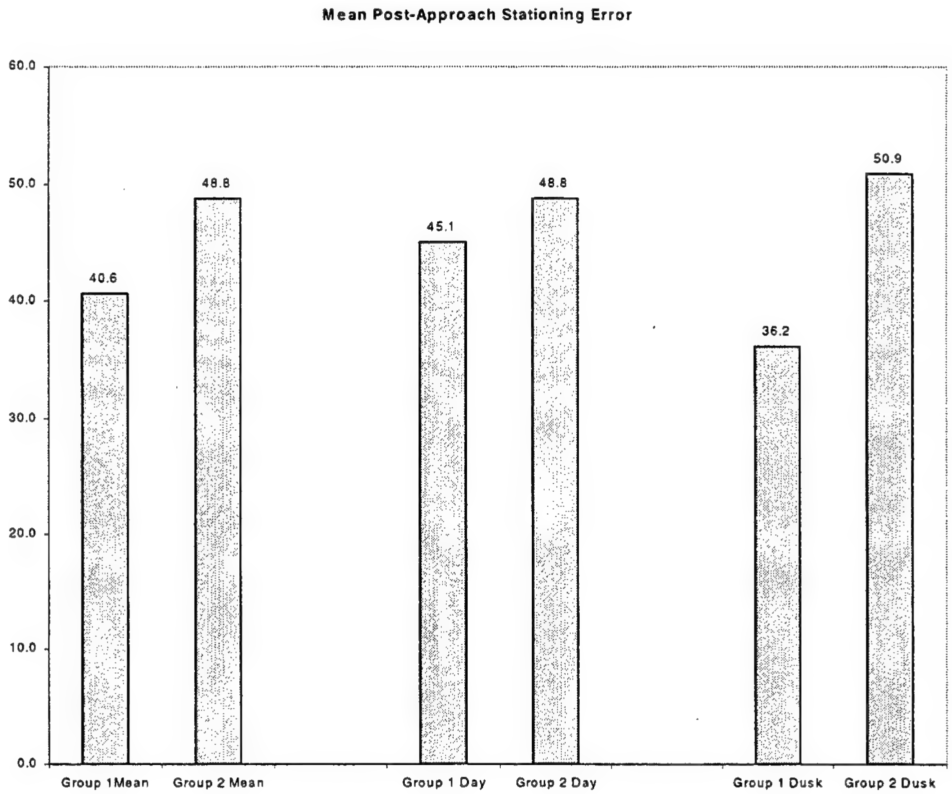


Figure 12: Comparison between groups for post-approach error.

The small difference in performance between subject groups was most apparent in the post-approach error measure for the dusk condition [Figure 12]. This small difference may be construed as evidence of a very slow deterioration in procedural memory over time, but the results of the statistical analysis do not support that hypothesis.

There was also a small difference between the two groups for the time-to-station dependent variable. On average, subjects in Group 1 took about ten seconds longer than subjects in Group 2 to reach station in the day lighting condition. In the dusk condition, subjects in both groups took, on average, the same amount of time.

4. Ship Track Data

During the computer simulation phase of the experiment, the positions and courses of the two ships were recorded every five seconds. A plot of these data for each trial provides an overhead visual representation of the simulated UNREP. Figure 13 depicts one trial.

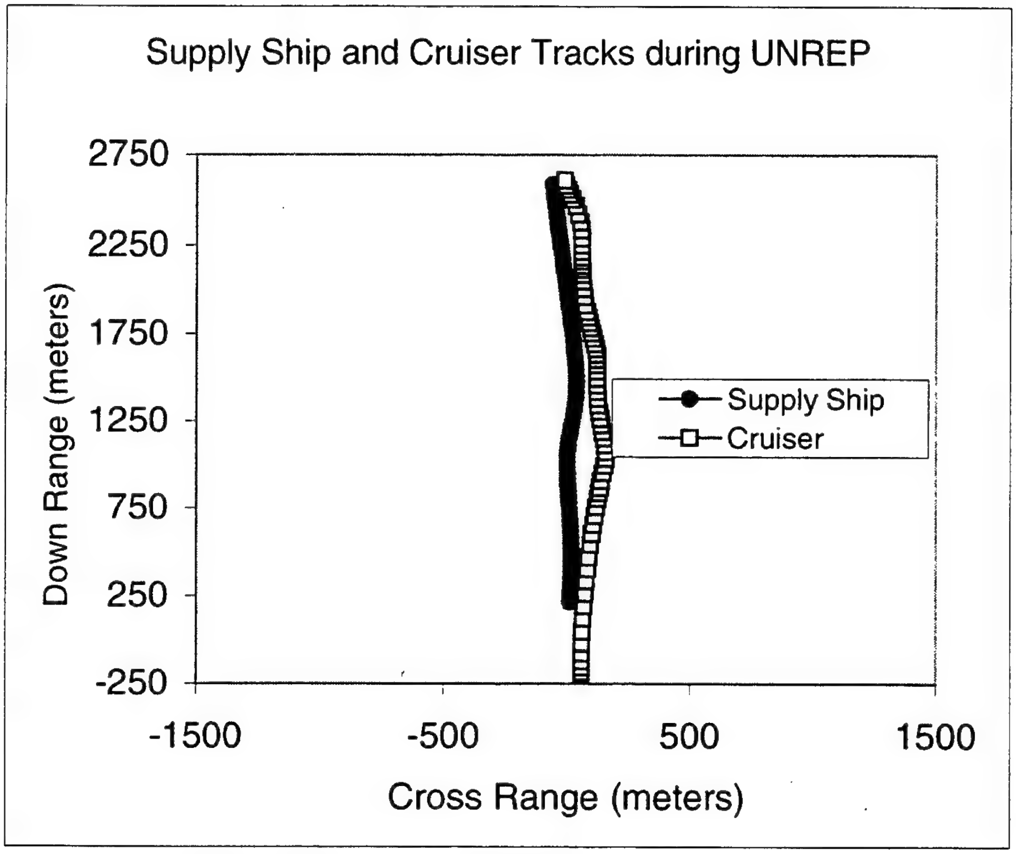


Figure 13: Example of position data collected during each trial.

Figure 14 depicts another useful plot of the position data collected during each trial. The plot shows the distance from the cruiser to the correct station and depicts the same UNREP as Figure 13. In this particular trial, the subject approached the correct station rapidly during the first 200 seconds. For the remainder of the trial, the subject attempted to reach and maintain station with small course and speed adjustments. Near the end of the trial the subject nearly achieved perfect station, as can be seen by the dip in the data almost to the X-axis after time 300.

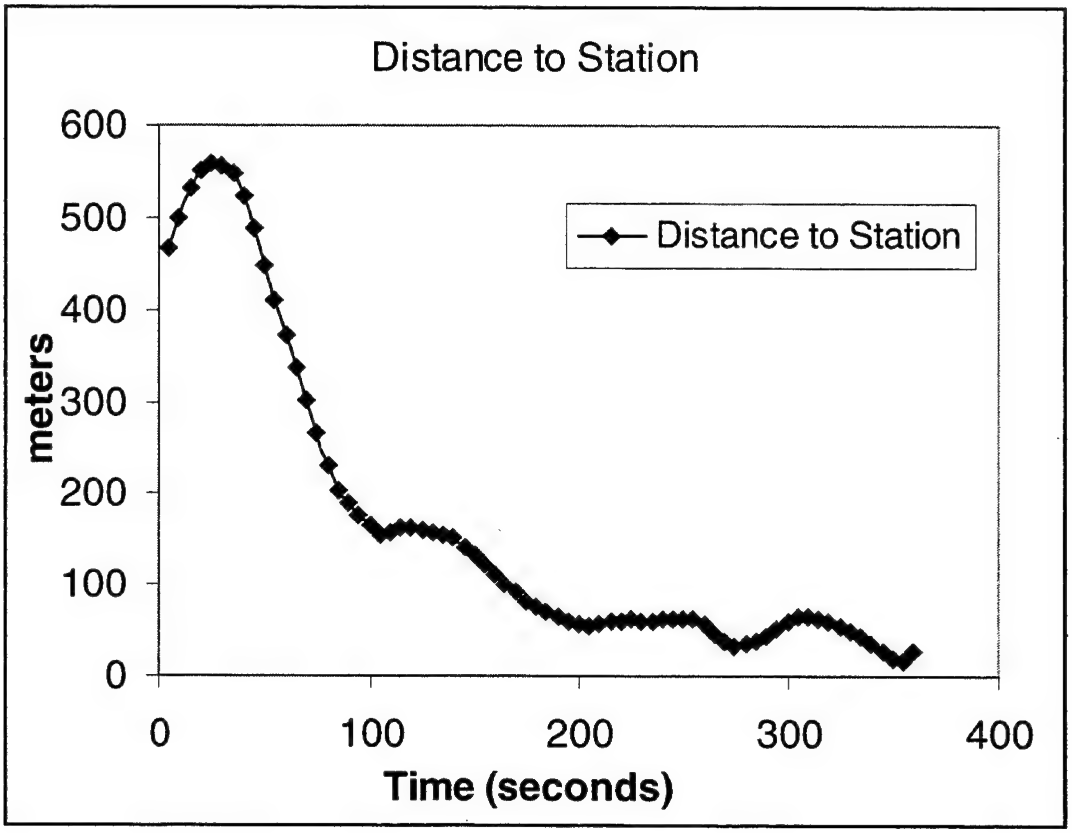


Figure 14: Plot of distance to correct station for UNREP depicted in figure 13.

C. PHASE II: WRITTEN EXAM

1. Measures of Performance

The written exam consisted of 18 questions. Of these, eight were multiple choice questions concerning ship handling fundamentals and regulations as described in *Naval Shiphandling* and the International Regulations for Prevention of Collisions at Sea, or Rules of the Road. The remaining ten questions asked the subject to visually identify the type of vessel, or the task being performed by the vessel, in a series of illustrations. Each illustration presented the day shapes or running lights of a type of vessel typically encountered while underway.

For the written exam portion of the experiment, subjects were assessed on the following measures of performance:

- Incorrect answers on Fundamentals portion: The number of incorrect answers on the first eight questions of the exam. The questions on this portion of the exam were multiple-choice. Possible scores were zero to eight.
- Incorrect answers on the Rules of the Road portion: The number of incorrect answers on the Rules of the Road portion of the exam. Each question on this portion of the exam required two written answers and was, therefore, scored as two points each. Possible scores were zero to 20.

A distinction between the two portions of the exam was made because in each portion both the aspect of declarative ship handling knowledge tested and the method of testing that knowledge differed. Questions in the first portion of the exam were based on written information found in *Naval Shiphandling* and the International Regulations for Prevention of Collisions at Sea, or "Rules of the Road." Below each question were four possible answers. The subjects were required to circle the answer they thought was correct.

In contrast, each question on the second portion of the exam presented visual representation of the day shapes or running lights of a type of vessel typically encountered while underway. Subjects were required to visually identify the type of vessel, or the task being performed by the vessel, in each illustration. Subjects were also required to identify the target angle of the vessel depicted. Target angle is similar to aspect, or orientation, and refers to the relative headings of each vessel. Target angle is an important concept in the Rules of the Road since it is often the single factor used to determine right-of-way when vessels encounter one another at sea.

2. Statistical Analysis

An initial examination of the data seemed to indicate two trends [Figure 13]. First, scores on the fundamental portion of the exam did not seem to provide evidence of a difference between groups (solid line in Figure 15). On the other hand, scores on the Rules of the Road portion of the exam seemed to strongly indicate a difference between groups (dashed line in Figure 15).

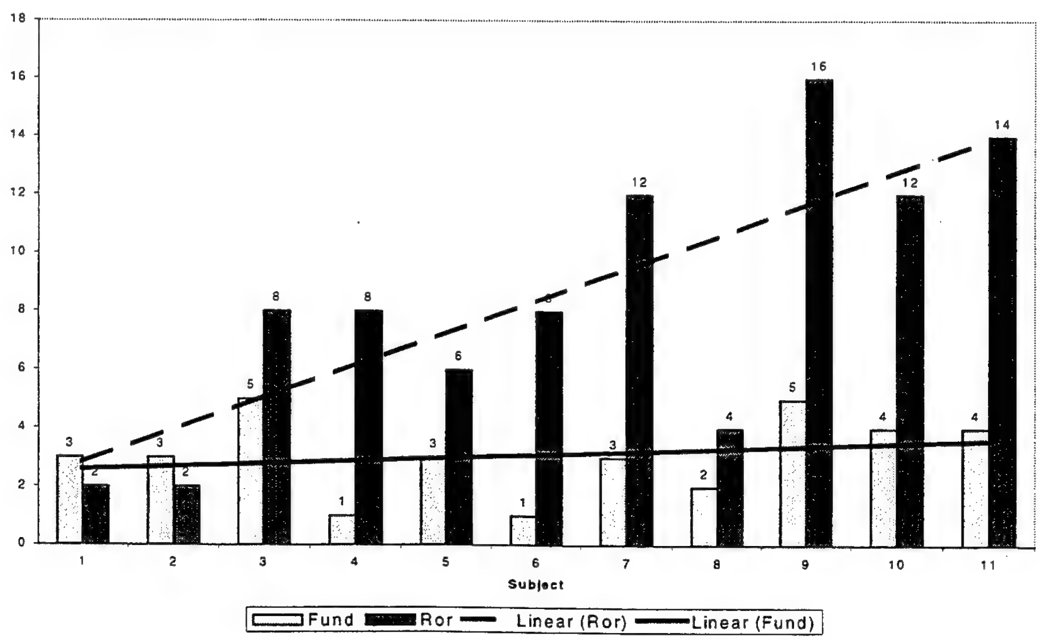


Figure 15: Questions missed on each portion of the exam (with trendlines). Subjects 1-5 are Group 1, Subjects 6-11 are Group 2.

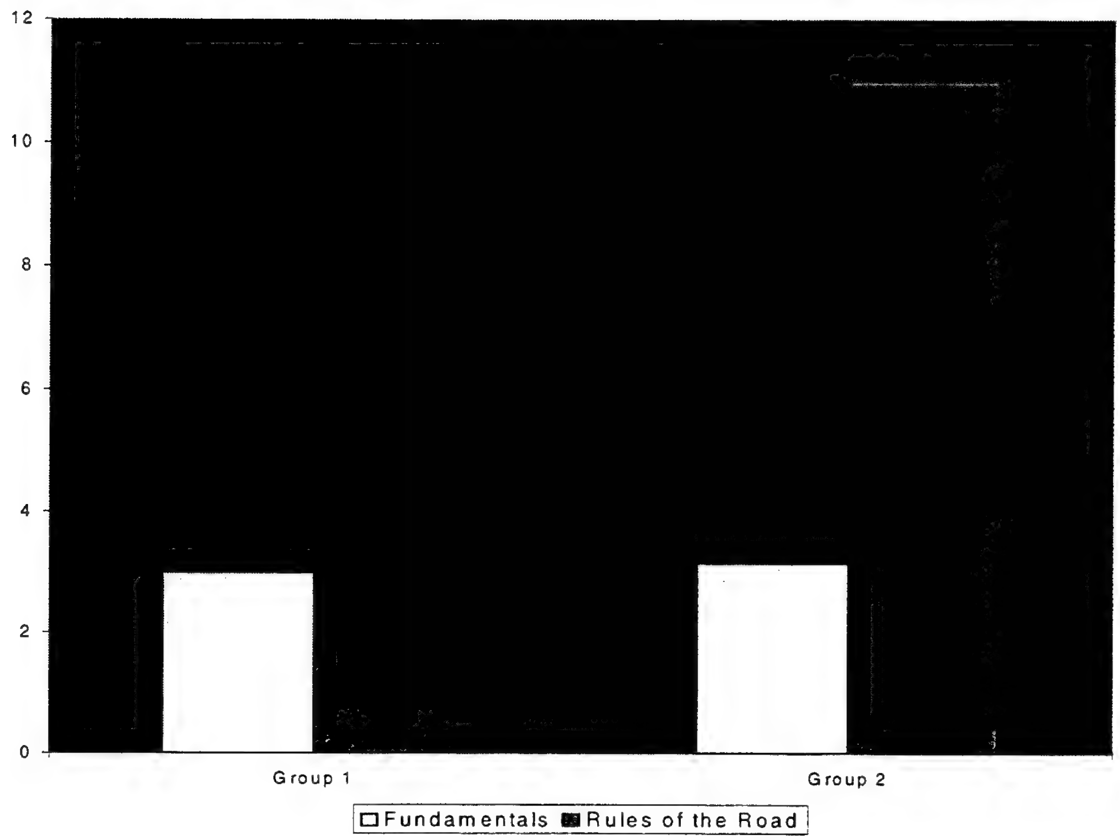


Figure 16: Between group comparison of exam scores.

Clearly, a comparison of the group means for the two portions of the exam illustrates the dichotomous results. For the Fundamentals portion of the exam, the group means are almost identical (group 1 mean of 3, group 2 mean of 3.16). For the Rules of the Road portion of the exam, the group means appear widely separated (group 1 mean of 5.2, group 2 mean of 11).

A number of methods were applied to the data to determine whether the difference suggested by the visual assessment was, in fact, significant.

A t-test showed no significance for fundamentals ($t = -0.1903$, $df = 9$, $p = 0.8533$), as was expected. A t-test for Rules of the Road did show statistical significance at the α=.05 level, ($t = -2.5125$, $df = 9$, $p = 0.0332$).

A Wilcoxon rank-sum test revealed no significance for the fundamentals portion of the exam, as was expected ($Z = -0.1882$, $p = 0.8507$). A Wilcoxon rank-sum test also did not reveal significance for the Rules of the Road portion of the exam ($Z = -1.9437$, $p = 0.0519$).

3. Randomization Test

Conflicting results between the t-test and Wilcoxon rank-sum test, as well as the nature of the data, suggested a distribution-free non-parametric approach at this stage. As a result, a randomization test was performed.

A randomization test is a form of permutation test based on randomization. The test is carried out by computing a test statistic for the experimental data, then randomly permuting the experimental data repeatedly and computing the test statistic from the permuted data each time (Kotz, Johnson, and Read, 1986). A p-value is obtained from the proportion of permutations that result in a computed test statistic as great or greater than the test statistic computed from the experimental data. The null hypothesis of a randomization test is that the measurement for a subject is independent of group assignment. The p-value obtained from a randomization test is thus the probability that, assuming the null hypothesis is true, one would observe a test statistic as extreme as that observed in the experiment. An important characteristic of a randomization test is that it is entirely independent of any assumptions about the distribution of the data under scrutiny.

For the exam data, the null hypothesis is that a subject's score on each portion of the exam is independent of what group that subject is in. To test this assumption free of assumptions concerning the distribution of the exam data, a randomization test was performed using 100,000 permutations for each portion of the exam. The randomization test showed no significance for fundamentals ($p = 0.89$), as was expected. For the Rules

of the Road portion of the exam data, the randomization test did show statistical significance ($\underline{p} = 0.047$) at the α=0.05 level.

IV. DISCUSSION

A. SUMMARY OF RESULTS

This research suggests Surface Warfare Officers experience a degradation of *declarative* knowledge of ship handling while away from sea. On the other hand, no evidence was found to reject the hypothesis that *procedural* knowledge of ship handling remains intact while away from sea.

The results of the simulated UNREP portion of the experiment revealed no significant differences between groups or lighting conditions. The results provide no evidence to support the assumption that procedural knowledge of ship handling deteriorates over time.

The results of the written exam portion of the experiment revealed a significant difference between two groups distinguished by time away from sea. On the visual identification portion of the exam, scores for Group 1 were significantly better than the scores of Group 2. No difference between groups was detected on the multiple-choice portion of the exam.

B. IMPLICATIONS

The results of this experiment indicate that, as expected, SWOs experience deterioration of ship handling proficiency while away from sea. However, the deterioration does not equally affect both procedural knowledge and declarative knowledge. Declarative knowledge was shown to have deteriorated while away from sea but procedural knowledge was not. The ship handling refresher training at Department Head School is directed primarily at procedural knowledge. The results of this experiment suggest that more time should be spent refreshing declarative knowledge instead.

Specifically, time away from sea was shown to have a significant effect on the ability of the subjects to visually identify signals displayed in accordance with the International Regulations for the Prevention of Collisions at Sea. Frequently, the signals described in these regulations provide the only common language between ships on the

high seas. Rapid and correct identification of a ship's signals can be vital to avoiding a collision or grounding. For instance, misidentifying the lights of a vessel aground (as a number of subjects did) could cause a ship to hit the same shoal itself. On the exam, every light and day shape question depicted just such a potentially dangerous situation.

Correct identification of lighting configurations is not only a matter of safety for one's own vessel. Some lighting configurations indicate that a vessel is in trouble and in need of assistance. For example, there is a lighting configuration for ships "not under command". Not under command means that the ship is uncontrollable, usually due to mechanical breakdown. A ship may be adrift for many days in this condition before encountering a potential rescuer. Food and water supplies may run low on such a ship and medical problems may arise among passengers and crew. Misidentification of the "not under command" lights could cause a potential rescue ship to steam past a disabled vessel without rendering assistance or notifying authorities.

Light signals are also used an aid to determine the relative heading of another ship (i.e. coming towards you, going away, on parallel course, etc). The relative heading of another ship usually determines whether it has the right-of-way. Although radar has greatly improved the ability to determine a ship's course, collisions still occur as a result of confusion about the right-of-way.

The small amount of time spent to refresh SWOs on the Rules of the Road may not be enough to offset the significant deterioration demonstrated by this research. If so, SWOs are returning to sea without the necessary declarative knowledge to stand bridge watch safely. When SWOs return to sea they are expected to train the junior SWOs, but officers may be standing bridge watches without the knowledge to effectively carry out that task.

There is no reason to believe the decay in knowledge is unique to NPS students. The large population of SWOs on shore duty likely exhibit the same deterioration detected in subjects at NPS. Additionally, the distinguishing factor between groups was not "time away from sea" per se, but rather "time since bridge watch". Consequently, there may be many SWOs at sea who experience decay in declarative knowledge of the Rules of the Road because they are not standing bridge watches.

C. FOLLOW-ON RESEARCH

There are a number of potential areas of follow-on research in this topic. For example, further research could attempt to detect changes in declarative and procedural knowledge of ship handling over smaller time spans.

Ships periodically remain in port for repair or refit for six months or more. During these periods, the SWOs on the ship are not exercising their ship handling skills. Furthermore, during these periods SWOs on the ship are heavily burdened with tasks related to repair and maintenance and do not have time to refresh ship handling skills. Follow-on research, with a greater number of subjects, could determine whether these SWOs are also at risk of decay in declarative ship handling knowledge over small time spans.

Another area of follow-on research could examine different ship handling tasks. Underway replenishment may be fundamentally different from other ship handling tasks. A repeat of the same experiment using a different task, such as plane guard or pier landing, might yield different results. A combination of two or more ship handling tasks could also be used. Subjects may exhibit decay in procedural knowledge of some tasks, but not others.

Follow-on research could also examine other areas of proficiency. For example, SWOs typically are required to achieve advanced shipboard fire-fighting qualifications in order to lead fire-fighting efforts in the event of a fire. Fire-fighting skills may also be in danger of decay during routine periods of inactivity.

Another interesting question is whether the results found by this experiment are also found in other similar populations. Subjects might be military pilots or vehicle drivers who spend significant periods away from their primary duty, for example.

The computer simulation created for this experiment could also be used for research in other topics. In particular, the Tactical Vectoring Equipment (TVE), a lighted visual navigation aid developed at NPS by LCDR Tom Evanoff (Evanoff, 1999; Krebs, Evanoff, and Sinai, 2000) was evaluated using a very similar computer simulation. The computer simulation developed for this experiment would provide an excellent tool for evaluating the effectiveness of the TVE as an aid to approach and station keeping for UNREP.

D. RECOMMENDATIONS

The results of this research suggest refresher training for SWOs should be revised. Before returning to sea after extended periods ashore, SWOs should be retrained in the declarative aspect of ship handling at least as much as the procedural aspect.

This research does not suggest ship handling refresher training should not address procedural tasks. Simulator training in an accurate and high fidelity simulator can be of benefit, even when the skills exercised are intact beforehand. Simulator training can be used to practice rare or dangerous tasks, or to gain familiarity with new procedures or equipment.

This research does suggest declarative knowledge of ship handling is susceptible to decay. Importantly, this decay occurs within a time period SWOs spend ashore as a normal part of their careers (often more than once). Decay of declarative knowledge should be expected during these periods. Refresher training should be weighted to address knowledge more heavily if it is more susceptible to decay. Specifically, refresher training for prospective department heads, executive officers and commanding officers should devote more time to the Rules of the Road.

APPENDIX A. WRITTEN EXAM

(correct answers are in italics)

SHIPHANDLING KNOWLEDGE QUIZ FOR SHIPHANDLING SKILL RETENTION THESIS

Date of Test: **Subject No.:** (Assigned during testing)

You have 20 minutes to complete the quiz. Circle the letter corresponding to one answer only for each multiple-choice question.

Section One: Naval Shiphandling Fundamentals

1. According to Crenshaw's *Naval Shiphandling*, which of the following are the six main sources of force affecting the motion of a ship in the water independent of any other vessel?

a) Current, Wind, Weather, Tide, Propellers, Tugs
b) Current, Wind, Weather, Propellers, Rudders, Mooring Lines
c) Current, Wind, Propellers, Rudders, Mooring Lines, Ground Tackle
d) Current, Wind, Propellers, Tugs, Rudders, Mooring Line

2. If a 600-foot vessel seen "beam-on" subtends an arc of 2° at the observer, what is the range of the vessel from the observer?

a) 1,500 yards
b) 3,000 yards
c) 4,500 yards
d) 6,000 yards

3. What is the course of a contact that bears 045° true and has a target angle of 225°?

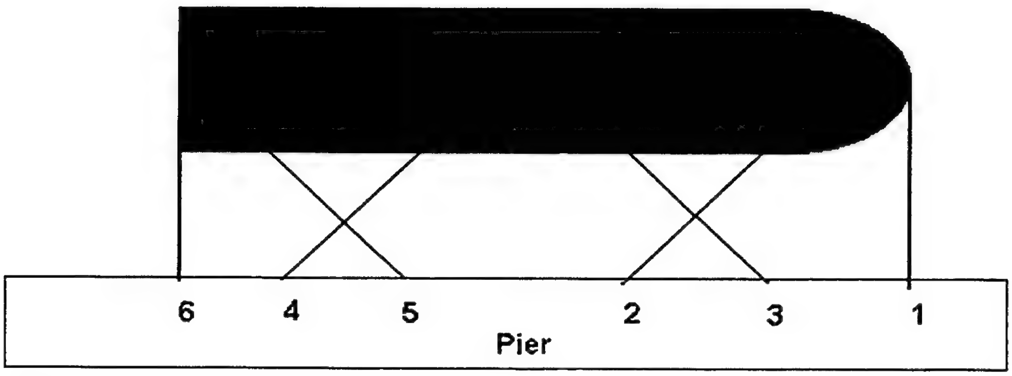
a) 045°
b) 135°
c) 225°
d) 000°

4. Your vessel is directly astern an aircraft carrier at a range of 36,000 yards. Formation speed is 13 knots and stationing speed is 30 knots. You are ordered to assume station 2,000 yards astern the carrier. Assuming no speed or course changes by the aircraft carrier, approximately how long will it take you to reach your new station?

a) 20 minutes
b) 45 minutes
c) 1 hour
d) 1 hour 20 minutes

5. What is the name of line 2 in the below figure of a vessel moored to a pier?

a) After bow spring
b) Forward quarter spring
c) Forward bow spring
d) After quarter spring



6. As a rule of thumb, approximately how far from your initial course should you turn when beginning a Williamson Turn?

a) 30°
b) 60°
c) 75°
d) 90°

7. What is the sound signal while in fog for a vessel restricted in her ability to maneuver?

a) 1 prolonged blast every two minutes
b) 2 prolonged blasts every two minutes
c) 1 prolonged blast followed by three short blasts every two minutes
d) 1 prolonged blast followed by two short blasts every two minutes

8. Nearly all single screw vessels, naval and civilian, have a tendency to do which of the following when backing?

a) Veer to port when viewed from astern
b) Veer to starboard when viewed from astern
c) Veer one way, then the other
d) None of the above

Section Two: Rules of the Road-Day Shapes

The following questions are short answer.

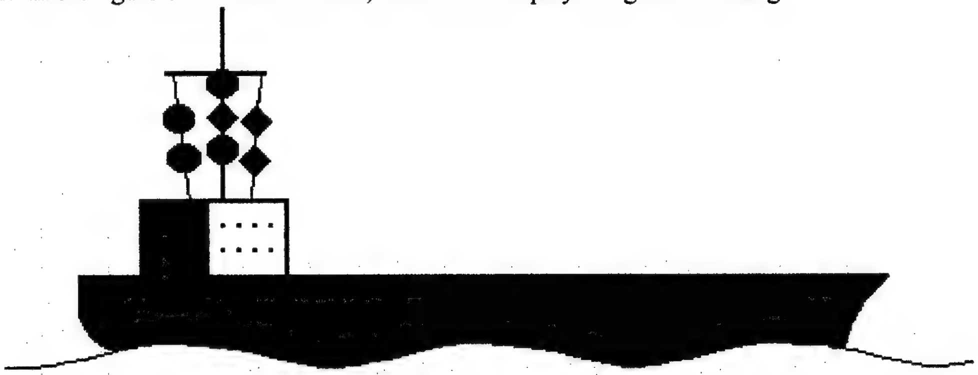
9. In the figure of the vessel below, what is the displayed signal indicating?

Answer: *Not under command*

10. In the figure of the vessel below, what is the displayed signal indicating?

Answer: *Aground*

11. In the figure of the vessel below, what is the displayed signal indicating?



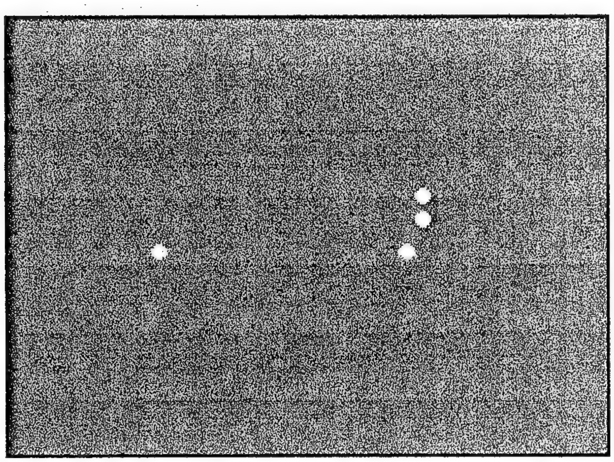
Answer: *Gear extended over the side (i.e. dredging, laying submarine cable, etc.)*

On what side of the vessel is it safe to pass? *Side with diamonds*

Section Three: Rules of the Road-Lights

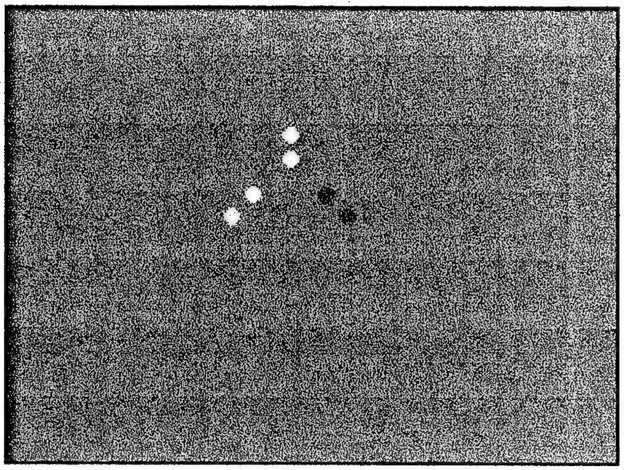
The following figures show the lights of other vessels as seen directly ahead at a range of 1 nautical mile or less. All lights are being correctly displayed in accordance with the International Rules of the Road.

12. In the figure of a vessel below, what is the displayed signal indicating and what is the approximate target angle (+/- 45°)?



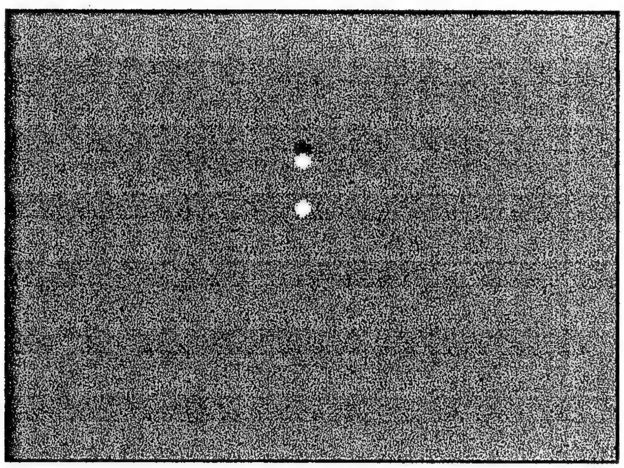
Answer: *Tug and tow < 200 meters long; TA = 90°*

13. In the figure of a vessel below, what is the displayed signal indicating and what is the approximate target angle (+/- 45°)?



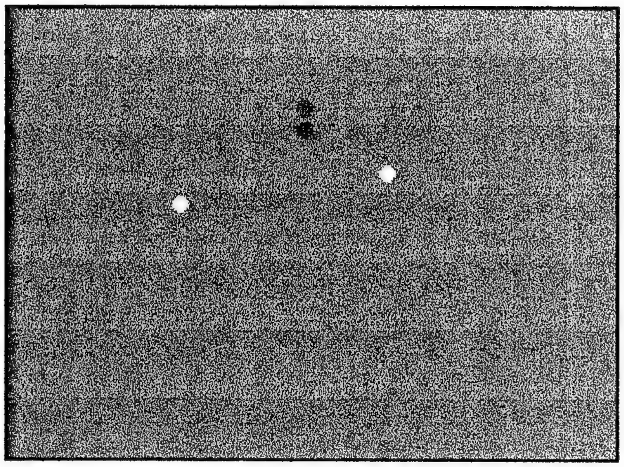
Answer: *Tug pushing ahead; TA = 000°*

14. In the figure of a vessel below, what is the displayed signal indicating and what is the approximate target angle (+/- 45°)?



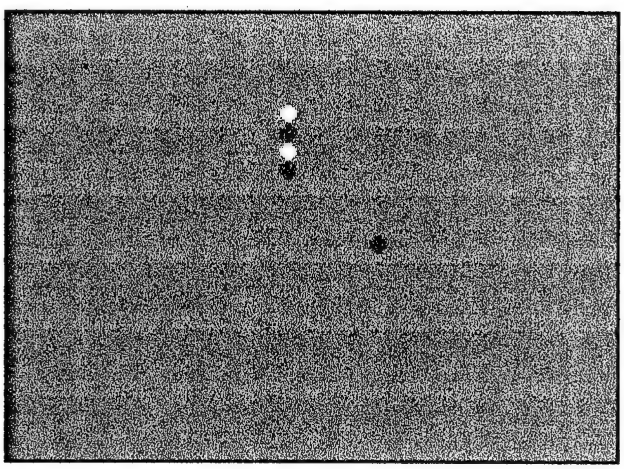
Answer: *Sailing vessel; TA = 90°*

15. In the figure of a vessel below, what is the displayed signal indicating and what is the approximate target angle (+/- 45°)?



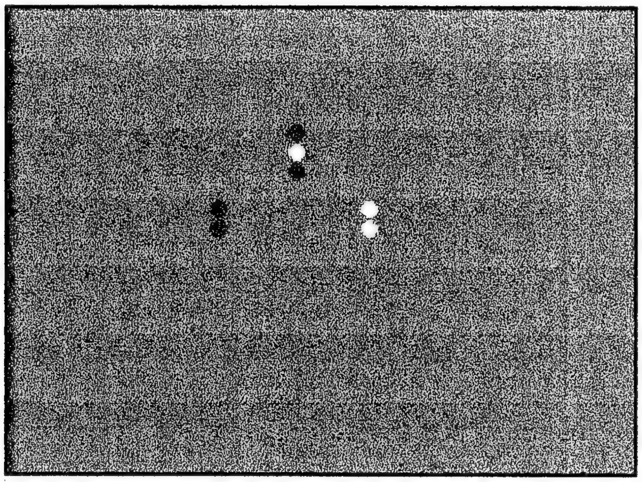
Answer: *Aground; TA = 90°*

16. In the figure of a vessel below, what is the displayed signal indicating and what is the approximate target angle (+/- 45°)?



Answer: *Restricted in ability to maneuver; TA = 270°*

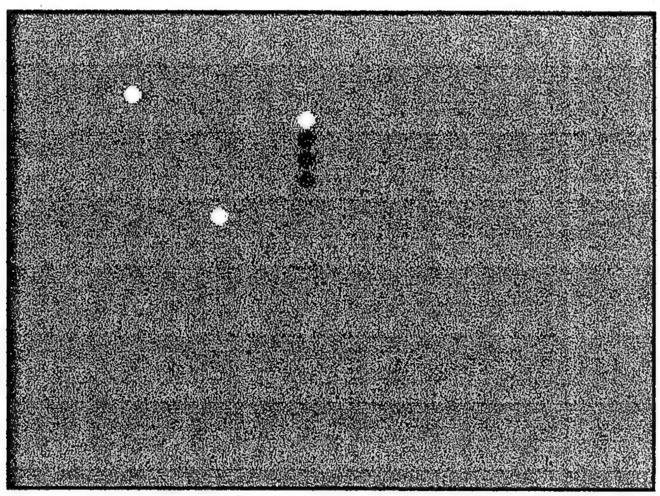
17. In the figure of a vessel below, what is the displayed signal indicating and what is the approximate target angle (+/- 45°)?



Answer: *Not making way (or at anchor), obstruction on side with red lights; TA= 000° or TA = 180°*

(this may be bow or stern aspect since all lights displayed are 360° arc of visibility)

18. In the figure of a vessel below, what is the displayed signal indicating and what is the approximate target angle (+/- 45°)?



Answer: *Constrained by draft; TA = 90°*

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APPENDIX B. SUBJECT QUESTIONNAIRE

QUESTIONNAIRE FOR SHIPHANDLING SKILL RETENTION THESIS

Date of Test: **Subject No.:** (Assigned during testing)

Last Name:____________________ **First Name:**____________________

Rank:_______

Age: _______ **Sex:** Male / Female **Citizenship:** U.S. Foreign:

____

Email Address: ______________________

Military Service: Navy Marine Army Air Force USCG Other: Civilian

Years of Active Military Service: __________

Military Designator/Warfare Specialty: _______________

1. Is your vision at least 20/20 or correctable to 20/20? **Yes / No**

2. Do you currently have any significant eye related health problems or significant problem
with your night vision? **Yes / No**

3. Provide a brief history of ships assigned and duties:

Ship Name	**Hull Type/No**	**Primary Duties**	**Date**
BUNKER HILL	CG 52	OPS(example)	Aug 95-Dec 97

4. How many months has it been since you last stood a bridge watch as OOD or Conning Officer?
1-3 **3-6** **6-9** **9-12** **12-18** **More than 18**

5. How many months has it been since you last conned a ship alongside during an UNREP?
1-3 **3-6** **6-9** **9-12** **12-18** **More than 18**

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APPENDIX C. SUBJECT BRIEF

SUBJECT TEST PROCEDURES AND CHECKLIST

- FORMS: Fill out questionnaire and consent form. Review for problems.
  - While subject fills out forms:
    - Compile subject files.
      1. Ensure move/rename previous subject "data" files.
      2. Type: **orderb**
      3. In ROOT, type: **chmod +x+x+x (ba_(subject number and initials)**)
         - Example (chmod +x+x+x ba_15abc)

    - Switch to HMD mode:
      1. In ROOT directory:
      2. Type: **cd /usr/gfx**
      3. Type: **/setmon –S 4@640x480_60**
      4. Type: **./stopgfx**
      5. Turn on black box
      6. Type: **./startgfx**

- BRIEF:
  - Review UNREP, explain lack of hydrodynamic effects and narrow separation from supply ship. Explain correct station:
    1. Fourth green flag just on cruiser rail.
    2. Phone-and-distance line perpendicular to both ships.

  - "In this simulation, you will be acting as the conning officer of a cruiser during six underway replenishments. Your ship will begin each UNREP in waiting station approximately 500 yards behind the supply ship. Your task is to make an approach and then maintain station on the supply ship. Each trial will begin with your ship at rest and the supply ship moving away from you at about 13.5 knots. When you are near the supply ship, the phone-and-distance line will automatically become visible."

  - **Review commands sheet.** "I will be acting as the helmsman lee helmsman. Commands are come right, come left or steady. Engine commands are engines ahead, engines back or engines steady. Each trial will last 6 mins. There will be a short pause between each trial if you need to rest."
  - TRIAL RUN:
    - "We will have one practice UNREP for you to get used to your ship and commands as well as to get a look at the supply ship. There is no phone-and-distance line in the practice UNREP."
    - Post **signs. Lights off.**
    - Type: **Bdatapull2 test7.adf**
    - After trial, answer any questions.

- When ready for actual trials:
  - Type: **ba_subject number and initials**
    - (example: ba_15abc)

- After last trial, turn on lights, let subject take a quick break.

- BRIEF EXAM:
- "You will now be given 20 minutes to complete a multiple choice and short answer quiz. No reference materials or calculators are allowed."

- Leave subject alone in separate room with quiz.

- **SAVE DATA FILE UNDER A NEW NAME.**
  - **Data will be in "data" file. Rename this file or else next subject data will overwrite it.**

To return HMD to normal mode, from ROOT:

1. Type: **cd/usr/gfx**
2. Type: **./setmon –x 1280x1024_60**
3. Type: **./stopgfx**
4. **TURN OFF BLACK BOX**
5. Type: **./startgfx**

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